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Age-Adjusted Analysis of Middle Ear Resonance Frequency Characteristics in Individuals with Temporomandibular Disorders

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Age-Adjusted Analysis of Middle Ear Resonance Frequency Characteristics in Individuals with Temporomandibular Disorders

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Abstract

Objective: This study aimed to evaluate middle ear resonance frequency characteristics in individuals with temporomandibular disorders (TMD) using wideband tympanometry, with particular emphasis on age-adjusted analysis.

Materials and Methods: A total of 40 participants were included, comprising 24 patients diagnosed with unilateral, chronic TMD and 16 healthy controls. All participants underwent comprehensive audiological assessment, including pure-tone audiometry, acoustic immittance, and wideband tympanometry. Middle ear resonance frequency outcomes were first compared using unadjusted analyses. Due to a significant age difference between groups, age-adjusted analyses were subsequently performed using analysis of covariance (ANCOVA).

Results: Unadjusted analyses suggested higher ipsilateral middle ear resonance frequency values in the TMD group compared with controls. However, after adjustment for age using ANCOVA, no statistically significant group differences were observed for the averaged resonance frequency outcomes.

Conclusion: Although unadjusted analyses suggested higher ipsilateral resonance frequency values in individuals with TMD, age-adjusted analyses demonstrated that these differences were not statistically significant, indicating that age may play an important role in the observed findings.

Keywords: Age-adjusted analysis, Analysis of covariance (ANCOVA), Middle ear resonance frequency, Temporomandibular disorders, Wideband tympanometry.

Introduction

Temporomandibular disorders (TMD) comprise a heterogeneous group of conditions affecting the temporomandibular joint, masticatory muscles, and associated structures and represent a common source of orofacial pain and functional limitation. In addition to classical musculoskeletal symptoms, patients with TMD frequently report otological complaints such as ear fullness, tinnitus, subjective hearing changes, and dizziness, even in the absence of identifiable middle or inner ear pathology (1,2).

The anatomical and functional proximity between the temporomandibular joint and the auditory system has long been proposed as a possible explanation for these symptoms. Costen first suggested that dysfunction of the temporomandibular joint could give rise to otological symptoms through mechanical or functional interactions (1). Subsequent studies proposed that altered mandibular biomechanics, abnormal reflex activity of the tensor tympani and stapedius muscles, or shared neural pathways may contribute to auditory manifestations in patients with TMD (3,4).

Wideband tympanometry has emerged as a valuable tool for the objective assessment of middle ear mechanics across a broad frequency range. Unlike conventional tympanometry, it enables evaluation of resonance frequency–related parameters that reflect stiffness and mass characteristics of the middle ear system (5–8).

Previous studies investigating middle ear resonance in individuals with TMD have reported inconsistent findings. Importantly, many studies did not adequately control for age, which is known to influence middle ear mechanics. Therefore, the present study aimed to evaluate middle ear resonance frequency characteristics in individuals with TMD using wideband tympanometry, with particular emphasis on age-adjusted analysis.

Materials and Methods

Study Population

This cross-sectional study was conducted at the Faculty of Dentistry, Istanbul Aydin University. Ethical approval was obtained from the Istanbul Aydın University Local Ethics Committee (2021/578), and all procedures were performed in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

A total of 40 individuals were included in the study, comprising 24 patients diagnosed with temporomandibular disorders (TMD) and 16 healthy control subjects. All participants were aged 18 years or older. Patients in the TMD group were referred from the Oral Diagnosis Department and had a documented history of unilateral TMD symptoms lasting longer than one year, and were therefore classified as having chronic TMD.

Inclusion criteria for the TMD group were as follows: (i) diagnosis of unilateral temporomandibular disorder, (ii) symptom duration exceeding 12 months, and (iii) absence of known middle or inner ear pathology based on otorhinolaryngological examination. Exclusion criteria included a history of otologic surgery, acute or chronic otitis media, sensorineural hearing loss, systemic diseases affecting the musculoskeletal system, or use of medications that could influence neuromuscular function.

The control group consisted of 16 individuals without temporomandibular complaints, otological symptoms, or a history of dental or otologic treatment. All control participants underwent routine dental and otorhinolaryngological examinations and were confirmed to have no middle or inner ear pathology.

Temporomandibular Disorder Assessment

Temporomandibular disorder diagnosis was established by an experienced specialist dentist using the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD). Clinical assessment included a detailed medical and dental history, evaluation of mandibular range of motion, joint sounds, muscle palpation, and pain localization.

The affected (ipsilateral) side was defined based on the side of dominant temporomandibular joint pain as reported by the patient and confirmed by clinical examination. In cases where pain was unilateral, the corresponding ear was considered the ipsilateral ear for subsequent analyses.

To support clinical diagnosis, digital occlusal analysis using the T-Scan system (Tekscan Inc., Boston, MA, USA) and electromyographic (EMG) evaluation of the masticatory muscles were performed. Occlusal force distribution, timing of occlusal contacts, and muscle activity patterns were assessed and used as adjunctive tools in the comprehensive evaluation of temporomandibular function.

Audiological Evaluation

All participants underwent a comprehensive audiological evaluation performed by an experienced audiologist prior to wideband tympanometric measurements. Pure-tone audiometry was conducted in a sound-treated booth using a calibrated clinical audiometer. Air-conduction thresholds were obtained at octave and inter-octave frequencies between 250 Hz and 8000 Hz. Bone-conduction thresholds were measured when indicated to exclude sensorineural or conductive hearing loss.

Only participants with hearing thresholds ≤ 20 dB HL at all tested frequencies were included in the study. Acoustic immittance testing was performed to assess middle ear status, and individuals showing abnormal tympanometric findings suggestive of middle ear pathology were excluded. These procedures ensured that all participants had normal peripheral auditory function and intact middle ear systems at the time of testing.

Wideband Tympanometry Protocol

Wideband tympanometry measurements were performed using a commercially available wideband acoustic immittance system calibrated according to the manufacturer's specifications. Measurements were conducted with the participant seated comfortably in an upright position, and the probe was carefully inserted into the external auditory canal to ensure an airtight seal.

Wideband tympanometry data were obtained across a broad frequency range under ambient pressure conditions. Middle ear resonance-related outcomes were derived from the wideband measurements. For analysis purposes, two averaged outcome measures were calculated: the mean of measurements obtained from frequency bands y13–y16 and the mean of measurements obtained from frequency bands y17–y20. These averaged values were used as representative resonance frequency-related parameters for subsequent statistical analyses.

In the TMD group, measurements from the ipsilateral ear (corresponding to the clinically affected temporomandibular joint side) were used for primary analysis. In the control group, measurements from both ears were included to reflect normative variability, acknowledging the potential limitation related to statistical independence.

All measurements were performed under identical testing conditions, and care was taken to minimize movement artifacts and environmental noise during data acquisition.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software (Version XX.X; IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for all variables and are presented as mean ± standard deviation (SD) for continuous variables and as frequencies and percentages for categorical variables.

Normality of continuous data was assessed using the Shapiro–Wilk test. Between-group comparisons of demographic variables were performed using the independent samples t-test with Welch correction for age and the chi-square test for sex distribution. A p-value of < 0.05 was considered statistically significant.

Initial group comparisons of middle ear resonance frequency–related outcomes were conducted using unadjusted analyses. Given the presence of a statistically significant age difference between the TMD and control groups, analysis of covariance (ANCOVA) was subsequently performed to evaluate group differences while controlling for age as a covariate. In the ANCOVA models, group (TMD vs. control) was entered as a fixed factor and age as a continuous covariate.

Two separate ANCOVA models were constructed for the averaged resonance-related outcome measures: (i) the mean of measurements derived from frequency bands y13–y16 and (ii) the mean of measurements derived from frequency bands y17–y20. Adjusted means, F values, p-values, and partial eta squared (η^2) were calculated to assess the magnitude of group effects after age adjustment.

All statistical analyses were conducted using two-tailed tests, and results were interpreted cautiously, particularly for borderline or non-significant findings.

Results

Demographic and Clinical Characteristics

A total of 40 participants were included in the study, consisting of 24 individuals with temporomandibular disorders (TMD) and 16 healthy controls. The demographic and clinical characteristics of the study population are summarized in Table 1.

Table 1. Demographic and Clinical Characteristics of the Study and Control Groups

Variable	TMD Group (n = 24)	Control Group (n = 16)	p-value
Age (years), mean ± SD	**33.3 ± 10.8**	**26.6 ± 2.2**	**0.008†**
Sex, n (%)			
Female	**17 (70.8%)**	**10 (62.5%)**	**0.836‡**
Male	**7 (29.2%)**	**6 (37.5%)**	
TMD symptom duration	**≥ 12 months (chronic)**	—	—

† Welch independent samples t-test
‡ Chi-square test

The TMD group comprised 17 females (70.8%) and 7 males (29.2%), with a mean age of 33.3 ± 10.8 years. All individuals in the TMD group had a chronic history of temporomandibular disorder symptoms lasting longer than one year. The control group included 10 females (62.5%) and 6 males (37.5%), with a mean age of 26.6 ± 2.2 years. A statistically significant difference in age was observed between the TMD and control groups ($p = 0.008$). In contrast, sex distribution did not differ significantly between groups ($p = 0.836$).

Unadjusted Resonance Frequency Comparisons

Initial unadjusted comparisons of middle ear resonance frequency–related outcomes demonstrated higher ipsilateral values in the TMD group compared with the control group. However, these differences did not consistently reach statistical significance across all outcome measures. Borderline results were interpreted cautiously and were considered suggestive rather than definitive.

Age-Adjusted Analysis of Resonance Frequency Outcomes

Given the significant age difference between the study groups, age-adjusted analyses were performed using analysis of covariance (ANCOVA), with group as a fixed factor and age entered as a covariate.

Averaged Outcome Derived from y13–y16

ANCOVA revealed no statistically significant group effect for the averaged resonance-related outcome derived from frequency bands y13–y16 after adjustment for age ($F = 1.60$, $p = 0.215$). The partial eta squared value indicated a small effect size ($\eta^2 = 0.046$). Adjusted mean values for each group are presented in Table 2.

Table 2. Age-Adjusted Comparison of Resonance Frequency Outcome (Mean of y13–y16)

Statistical analysis: ANCOVA (Group as fixed factor, Age as covariate)

Source	**df**	**F**	**p-value**	**Partial η^2**
Group (TMD vs Control)	1	**1.60**	**0.215**	**0.046**
Age (covariate)	1	2.96	0.093	0.082
Error	33			

Estimated Marginal Means (Age-adjusted)

Group	**Adjusted Mean**	**Standard Error**
Control	15.37	0.54
TMD	14.01	0.58

Model notes:
N = 36 (TMD = 20, Control = 16); age centered at overall mean (31 years)

Averaged Outcome Derived from y17–y20

Similarly, no statistically significant group effect was observed for the averaged resonance-related outcome derived from frequency bands y17–y20 following age adjustment ($F = 2.32$, $p = 0.137$). The corresponding effect size was small to moderate ($\eta^2 = 0.066$). Age-adjusted group means are summarized in Table 3.

Table 3. Age-Adjusted Comparison of Resonance Frequency Outcome (Mean of y17–y20)

Statistical analysis: ANCOVA (Group as fixed factor, Age as covariate)

Source	**df**	**F**	**p-value**	**Partial η²**
Group (TMD vs Control)	1	**2.32**	**0.137**	**0.066**
Age (covariate)	1	0.29	0.591	0.009
Error	33			

Estimated Marginal Means (Age-adjusted)

Group	**Adjusted Mean**	**Standard Error**
Control	13.44	0.62
TMD	15.23	0.66

Model notes:
N = 36 (TMD = 20, Control = 16); age centered at overall mean (31 years)

Summary of Findings

Overall, while unadjusted analyses suggested higher ipsilateral resonance frequency–related values in individuals with temporomandibular disorders, age-adjusted analyses did not demonstrate statistically significant differences between the TMD and control groups.

Discussion

Interpretation of the Findings

The present study evaluated middle ear resonance frequency characteristics in individuals with temporomandibular disorders using wideband tympanometry, with particular emphasis on controlling for age as a potential confounding factor. The primary finding of this study is that, although unadjusted analyses suggested higher ipsilateral resonance frequency–related values in the TMD group compared with healthy controls, these differences were no longer statistically significant after adjustment for age.

These findings highlight the importance of accounting for age-related effects when interpreting middle ear resonance characteristics. Previous studies investigating the relationship between temporomandibular disorders and middle ear function have reported inconsistent results. Some authors have reported higher ipsilateral resonance frequencies in patients with unilateral TMD, suggesting increased stiffness of the middle ear system, whereas others failed to demonstrate clear differences between affected and unaffected ears or control groups. The present results suggest that at least part of the variability observed in earlier studies may be attributable to differences in age distribution rather than to temporomandibular disorder–related mechanisms alone.

Age-related changes in middle ear mechanics have been well documented, even in individuals with normal hearing. Structural and biomechanical alterations affecting the tympanic membrane, ossicular chain, and supporting ligaments may influence resonance characteristics over time. In the current study, the TMD group was significantly older than the control group, and age-adjusted analyses demonstrated that the observed unadjusted differences were attenuated when age was included as a covariate. This finding underscores the need for cautious interpretation of resonance frequency differences in cross-sectional TMD studies that do not adequately control for age.

Importantly, the absence of statistically significant age-adjusted group differences does not exclude a potential interaction between temporomandibular disorders and middle ear mechanics. Rather, the findings suggest that any such relationship is likely to be subtle, multifactorial, and influenced by individual characteristics such as age, chronicity of symptoms, and neuromuscular adaptation. The small-to-moderate effect sizes observed in the present analyses further support the notion that TMD-related changes in middle ear resonance, if present, are modest and may not be readily detectable without larger and more homogeneous study populations.

Limitations

Several limitations of this study should be acknowledged. First, the sample size was relatively small, which may have limited the statistical power to detect subtle differences in middle ear resonance frequency between groups. Consequently, the present findings should be interpreted as hypothesis-generating rather than definitive.

Second, the study employed a cross-sectional design, which precludes conclusions regarding causality or temporal relationships between temporomandibular disorders and middle ear resonance characteristics. Longitudinal studies assessing changes in resonance frequency before and after TMD treatment would provide more robust evidence regarding potential causal mechanisms.

Third, although age was statistically controlled using ANCOVA, other potential confounding factors such as symptom severity, specific TMD subtypes, and psychosocial variables were not fully quantified. In particular, pain intensity scores were not consistently available due to the retrospective nature of clinical records, and subgroup analyses according to TMD subtype could not be performed.

Finally, in the control group, measurements from both ears were included to reflect normative variability. While this approach increases the representativeness of control data, it may partially violate assumptions of statistical independence. This methodological choice was acknowledged and addressed cautiously in the interpretation of results.

Clinical Implications and Future Directions

From a clinical perspective, the findings of this study suggest that middle ear resonance frequency alterations observed in individuals with temporomandibular disorders should be interpreted with caution, particularly in the absence of age-matched control groups. Wideband tympanometry may provide useful complementary information in the evaluation of patients with TMD and otological complaints; however, resonance frequency measures alone should not be considered diagnostic of TMD-related auditory involvement.

Future studies should aim to include larger, age-matched cohorts and standardized assessments of TMD severity and subtype. Longitudinal designs evaluating resonance frequency changes following conservative or interventional TMD treatment may help clarify whether observed alterations represent reversible functional changes or long-term biomechanical adaptations. Additionally, integration of wideband tympanometry with neuromuscular assessments, such as electromyography and digital occlusal analysis, may provide a more comprehensive understanding of the complex interactions between temporomandibular disorders and middle ear function.

Authors' Contributions

Conceptualization: **S.G.** Study design: **S.G., B.E.** Data collection: **S.G., B.E.** Clinical assessment: **S.G., B.E.** Audiological measurements: **B.E.** Statistical analysis: **S.G.** Interpretation of data: **S.G.** Manuscript drafting: **S.G.** Critical revision of the manuscript: **S.G.**

The author has read and approved the final version of the manuscript.

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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